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The National Interim Primary Drinking Water Regulations published herein were promulgated on December 24, 1975, in accordance with the provisions of the Safe Drinking Water Act (Public Law 93-523). Additional Interim Primary Regulations for radioactivity in drinking water were promulgated on July 9. 1976. These regulations become effective on June 24, 1977, and become in essence the standards by which all public drinking water supplies are judged.

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NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER SUPPLY

APPENDIX IV

Dosimetric Calculations for Man-Made Radioactivity

A. *Calculations Based on NBS Handbook 69*

The dose rate from radioactivity in drinking water is calculated on the basis of a 2 liter daily* intake. Except for tritium and strontium-90, see below, the concentrations of man-made radionuclides causing 4 millirem per year have been calculated using the data in NBS Handbook 69 (1) and are tabulated in Table IV-2A and IV-2B. The dose models used in preparing Handbook 69 are outlined in reference 2. Maximum Contaminant Levels are defined in terms of the annual dose equivalent to the total body or any internal organ. Handbook 69 lists the critical organ for each radionuclide. Often the total body is listed as the critical organ. The 168 hour maximum permissible concentrations for ingestion in Handbook 69 are not calculated on the basis of the same annual dose to each critical organ as in the Interim Regulations, rather different organ doses are permitted by occupational radiation protection limits (ORL), Table IV-1.

TABLE IV-1. Occupational Radiation Limits

(ORL)	
Critical Organ	ORL (rems)
Total body	5
Gonads	5
Thyroid	30
Bone	29.1 (a)
Other Organs	15

(a) Based on the alpha energy deposited in bone by 0.1 μCi of radium-226.

The maximum permissible concentrations for a 168 hour week, MPC, in Handbook 69, assume ingestion at 2.2 liters per day and are in units of μCi per cc. The various numerical factors can be combined to find C_4, the concentration causing 4 mrem per year from 2 liters daily ingestion of drinking water as follows:

$$C_4 = 4.4 \times 10^6 \times \frac{MPC}{ORL} \ldots\ldots \text{pCi per liter}$$

Critical organs are identified by boldface type in Handbook 69 so that an appropriate ORL can be selected from Table IV-1.

To illustrate, a sample calculation, taken from page 24 of Handbook 69 is given:

*The recent ICRP publication #23, "Report of the Task Group on Reference Man," (3) gives the total daily water intake as 3 liters, 1.95 liters by fluid intake; the balance by food and food oxidation. Almost all of the fluid intake is from tap water and water based drinks (Page 360).

Radionuclide

Beryllium-7 MPC (168 hours) = 0.02 uCi/cm³

Listed critical organ GI(LLI) gastrointestional tract (lower large intestine)

$$C_4 = 4.4 \times 10^6 \times \frac{0.02}{15} \frac{\text{pCi}}{\text{l}} = 5867 \text{ pCi/l}$$

$$= 6000 \text{ pCi/l}$$

Rounding is appropriate since the values in Handbook 69 are given to one significant figure.

Calculation of the dose resulting from the ingestion of drinking water containing a known mixture of radionuclides is straightforward. Let A, B, . . . be the concentrations, in pCi per liter, of isotopes a, b, . . . in the water and let $C_4{}^A(X)$ be the average annual concentrations of isotope A yielding 4 millirem per year to organ X, $C_4{}^B(X)$ the same quantity for B, etc. The total annual dose to organ X in one year is, then

$$\left[\frac{A}{C_4{}^A(X)} + \frac{B}{C_4{}^B(X)} + \ldots\right] \times 4 \text{ millirem}$$

Therefore, the 4 millirem limit is not exceeded if

$$\left[\frac{A}{C_4{}^A(X)} + \frac{B}{C_4{}^B(X)} + \ldots\right] \leq 1.0$$

It should be noted that although limits for the various radionuclides may be based on different critical organs, the resultant dose is additive with respect to a specific organ when the total body is the designated critical organ for one of the radionuclides. For example, consider drinking water which has on an annual basis a strontium-90 concentration of 4 pCi/l and a tritium concentration of 15,000 pCi/l. The annual dose to bone marrow from the strontium-90 is 2 mrem. The total body dose from the tritium is 3 mrem annually. Even though the annual concentration of each contaminant alone is permissible, the total dose to bone marrow is 5 mrem annually and therefore the MCL is exceeded. Tabular values for C_4 for photon and beta emitters are listed in Table IV-2A and IV-2B below.

B. *The Dose from Tritium and Strontium-90 in Drinking Water*

For the majority of radionuclides, the models given in Handbook 69 to estimate doses to occupationally exposed workers are also appropriate for environmental contaminants. They are not, however, appropriate for all man-made radionuclides, particularly tritium and strontium-90. Concentrations yielding 4 millirem annually for these radionuclides are given in Table A of the Interim Regulations and listed in Table IV-2A.

Some radionuclides are isotopes of elements which are incorporated into organic molecules within the body so that the single exponential excretion models assumed in the development of Handbook 69 underestimate the dose. An example is tritium where two or three exponentials may be needed to describe the dose-time relationship of ingested tritium (4). Some investigators have estimated that following chronic ingestion organically bound tritium may increase the dose by a factor of 1.4 to 1.5 over that predicted by Handbook 69 (5). Such estimates are too high because organically bound tritium irradiates the total body mass, and not just the mass of body water, as assumed in the model used in Handbook 69 (2).

Consideration of the daily intake of hydrogen and water shows that the tritium concentration (specific activity) in any organ is no greater than 120% of the tritium concentration in body water. The concentration of tritium in body water following chronic ingestion is T/3 where T is daily intake of tritium in pCi and the total water intake, including that in food, is 3 liters per day (3). Water content by weight of any organ does not exceed 80 percent (4). Therefore, equilibrium concentration of tritium in any organ due to its water content, can not exceed 0.8 T/3 = .267 T pCi/kg.

Because of organically bound hydrogen an organ's hydrogen (and tritium) content is greater than that due to water alone. The daily hydrogen intake is .35 kg per day (3) and, since no organ contains more than 11 percent hydrogen by weight (4), the maximum tritium concentration in any organ following chronic ingestion is .11 T/.35 = .314 T pCi/kg. The specific activity of tritium in any organ due to bound and unbound hydrogen exceeds that due to its water content alone by the ratio .314/.267 = 1.18. Therefore, the dose to any organ due to organically bound tritium exceeds the dose to body water, given in Handbook 69, by no more than about twenty percent.

The Agency is aware that the ICRP is developing new tritium dose models more suitable for environmental sources of tritium exposure than the model used in Handbook 69. Until these models are published and recommended by the Agency, the maximum contaminant level for tritium is calculated on the basis of 80 percent of the value calculated using NBS Handbook 69.* For tritium in drinking water:

$$C_4 = 0.8 \times 4.4 \times 10^6 \times \frac{0.03}{5} = 21{,}120 \text{ pCi/l}$$
$$= \underline{20{,}000 \text{ pCi/l}}$$

The maximum contaminant level for strontium-90 in the Interim Regulations is based on the dose model used by the Federal Radiation Council (FRC) to predict the dose to bone marrow (6). According to the FRC model a continuous daily intake of 200 pCi per day of strontium-90 will result in a body burden of 50 pCi per gram of calcium in bone. The annual

*n.b. In accordance with current guidance to Federal agencies, a quality factor of 1.7, as in Handbook 69, is used in this calculation.

dose rate to bone marrow from this body burden would be 50 mrem per year (7). Therefore, continuous ingestion of 16 pCi per day would result in 4 mrem per year, the limit for man-made radionuclides in drinking water. For two liters ingestion of water per day:

$$C_4 = \frac{16\ \text{pCi}}{2} = 8\ \text{pCi/l}$$ Sr · 90

C. *Concentrations yielding an Annual Dose of 4 Millirem*

Tables IV-2A and IV-2B give C_4 the annual average concentrations for man-made radionuclides which are assumed to yield an annual dose of 4 millirem to the indicated organ. Table IV-2A comprises those nuclides having half-lives greater than one day. Table IV-2B contains shorter half-life radionuclides not expected to appear in drinking water supplies. Ingestion at a rate of 2.0 liters per day is assumed. The values shown were calculated from the Maximum Permissible Concentrations listed in Handbook 69 (1) as outlined above.

TABLE IV-2A. *Annual Average Concentrations Yielding 4 Millirem per Year for a Two Liter Daily Intake*

(Half-life greater than 24 hours)

Radionuclide	Critical Organ	C_4 (pCi/l)
Tritium	Total Body	20,000
$^{4}Be^{7}$	GI (LLI)	6,000
$^{6}C^{14}$	Fat	2,000
$^{11}Na^{22}$	Total Body	400
$^{15}P^{32}$	Bone	30
$^{16}S^{35}$	Testis	500
$^{17}Cl^{36}$	Total Body	700
$^{20}Ca^{45}$	Bone	10
$^{20}Ca^{47}$	Bone	80
$^{21}Sc^{46}$	GI (LLI)	1,000
$^{21}Sc^{47}$	GI (LLI)	300
$^{21}Sc^{48}$	GI (LLI)	80
$^{23}V^{48}$	GI (LLI)	90
$^{24}Cr^{51}$	GI (LLI)	6,000
$^{25}Mn^{52}$	GI (LLI)	90
$^{25}Mn^{54}$	GI (LLI)	300
$^{26}Fe^{55}$	Spleen	2,000
$^{26}Fe^{59}$	GI (LLI)	200
$^{27}Co^{57}$	GI (LLI)	1,000
$^{27}Co^{58}$	GI (LLI)	9,000
$^{27}Co^{60}$	GI (LLI)	100
$^{28}Ni^{59}$	Bone	300
$^{28}Ni^{63}$	Bone	50
$^{30}Zn^{65}$	Liver	300
$^{32}Ge^{71}$	GI (LLI)	6,000
$^{33}As^{73}$	GI (LLI)	1,000
$^{33}As^{74}$	GI (LLI)	100
$^{33}As^{76}$	GI (LLI)	60
$^{33}As^{77}$	GI (LLI)	200

$^{34}Se^{75}$	Kidney	900
$^{35}Br^{82}$	GI (LLI)	100
$^{37}Rb^{86}$	Total Body	600
$^{37}Rb^{87}$	Pancreas	300
$^{38}Sr^{85}$	GI (SI)	21,000
$^{38}Sr^{89}$	Bone	20
$^{38}Sr^{89}$	Bone Marrow (FRC)	80
$^{38}Sr^{90}$	Bone Marrow (FRC)	8
$^{39}Y^{90}$	GI (LLI)	60
$^{39}Y^{91}$	GI (LLI)	90
$^{40}Zr^{93}$	GI (LLI)	2,000
$^{40}Zr^{95}$	GI (LLI)	200
$^{41}Nb^{93m}$	GI (LLI)	1,000
$^{41}Nb^{95}$	GI(LLI)	300
$^{42}Mo^{99}$	Kidney	600
$^{43}Tc^{96}$	GI(LLI)	300
$^{43}Tc^{97m}$	GI(LLI)	1,000
$^{43}Tc^{97}$	GI(LLI)	6,000
$^{43}Tc^{99}$	GI(LLI)	900
$^{44}Ru^{97}$	GI(LLI)	1,000
$^{44}Ru^{103}$	GI(LLI)	200
$^{44}Ru^{106}$	GI(LLI)	30
$^{45}Rh^{105}$	GI(LLI)	300
$^{46}Pd^{103}$	GI(LLI)	900
$^{46}Pd^{109}$	GI(LLI)	300
$^{47}Ag^{105}$	GI(LLI)	300
$^{47}Ag^{110m}$	GI(LLI)	90
$^{47}Ag^{111}$	GI(LLI)	100
$^{48}Cd^{109}$	GI(LLI)	600
$^{48}Cd^{115m}$	GI(LLI)	90
$^{48}Cd^{115}$	GI(LLI)	90
$^{49}In^{115}$	GI(LLI)	300
$^{50}Sn^{113}$	GI(LLI)	300
$^{50}Sn^{125}$	GI(LLI)	60
$^{51}Sb^{122}$	GI(LLI)	90
$^{51}Sb^{124}$	GI(LLI)	60
$^{51}Sb^{125}$	GI(LLI)	300
$^{52}Te^{125m}$	Kidney	600
$^{52}Te^{127m}$	Kidney	200
$^{52}Te^{127}$	GI(LLI)	900
$^{52}Te^{129m}$	GI(LLI)	90
$^{52}Te^{129}$	GI(S)	2,000
$^{52}Te^{131m}$	GI(LLI)	200
$^{52}Te^{132}$	GI(LLI)	90
$^{53}I^{126}$	Thyroid	3
$^{53}I^{129}$	Thyroid	1
$^{53}I^{131}$	Thyroid	3
$^{55}Cs^{131}$	Total Body	20,000
$^{55}Cs^{134}$	GI(S)	20,000
$^{55}Cs^{135}$	Total Body	900
$^{55}Cs^{136}$	Total Body	800
$^{55}Cs^{137}$	Total Body	200
$^{56}Ba^{131}$	GI(LLI)	600

$^{56}Ba^{140}$	GI(LLI)	90
$^{57}La^{140}$	GI(LLI)	60
$^{58}Ce^{141}$	GI(LLI)	300
$^{58}Ce^{143}$	GI(LLI)	100
$^{59}Pr^{143}$	GI(LLI)	100
$^{61}Pm^{149}$	GI(LLI)	100
$^{62}Sm^{151}$	GI(LLI)	1,000
$^{62}Sm^{153}$	GI(LLI)	200
$^{63}Eu^{152}$	GI(LLI)	60
$^{63}Eu^{154}$	GI(LLI)	200
$^{63}Eu^{155}$	GI(LLI)	600
$^{64}Gd^{153}$	GI(LLI)	600
$^{65}Tb^{160}$	GI(LLI)	100
$^{66}Dy^{166}$	GI(LLI)	100
$^{67}Ho^{166}$	GI(LLI)	90
$^{68}Er^{169}$	GI(LLI)	300
$^{69}Tm^{170}$	GI(LLI)	100
$^{69}Tm^{171}$	GI(LLI)	1,000
$^{70}Yb^{175}$	GI(LLI)	300
$^{71}Lu^{177}$	GI(LLI)	300
$^{72}Hf^{181}$	GI(LLI)	200
$^{73}Ta^{182}$	GI(LLI)	100
$^{74}W^{181}$	GI(LLI)	1,000
$^{74}W^{185}$	GI(LLI)	300
$^{75}Re^{183}$	GI(LLI)	2,000
$^{75}Re^{186}$	GI(LLI)	300
$^{75}Re^{187}$	GI(LLI)	9,000
$^{76}Os^{185}$	GI(LLI)	200
$^{76}Os^{191}$	GI(LLI)	600
$^{76}Os^{193}$	GI(LLI)	200
$^{77}Ir^{190}$	GI(LLI)	600
$^{77}Ir^{192}$	GI(LLI)	100
$^{78}Pt^{191}$	GI(LLI)	300
$^{78}Pt^{193m}$	GI(LLI)	3,000
$^{78}Pt^{193}$	Kidney	3,000
$^{78}Pt^{197}$	GI(LLI)	300
$^{79}Au^{196}$	GI(LLI)	600
$^{79}Au^{198}$	GI(LLI)	100
$^{81}Tl^{204}$	GI(LLI)	300
$^{82}Pb^{203}$	GI(LLI)	1,000
$^{83}Bi^{206}$	GI(LLI)	100
$^{83}Bi^{207}$	GI(LLI)	200
$^{91}Pa^{233}$	GI(LLI)	300

TABLE IV-2B

Annual Average Concentrations Yielding 4 Millirem per Year for a Two Liter Daily Intake (Half-life less than 24 hours)

Radionuclide	*Critical Organ*	C_i (pCi/l)
$^{9}F^{18}$	GI(SI)	2,000
$^{14}Si^{31}$	GI(S)	3,000
$^{17}Cl^{38}$	GI(S)	1,000

$^{19}K^{42}$	GI(S)	900
$^{25}Mn^{56}$	GI(LLI)	300
$^{27}Co^{58m}$	GI(LLI)	300
$^{28}Ni^{65}$	GI(LLI)	300
$^{29}Cu^{64}$	GI(LLI)	900
$^{30}Zn^{69m}$	GI(LLI)	200
$^{30}Zn^{69}$	GI(S)	6,000
$^{31}Ga^{72}$	GI(LLI)	100
$^{38}Sr^{85m}$	Total Body	900
$^{38}Sr^{91}$	GI(LLI)	200
$^{38}Sr^{92}$	GI(ULI)	200
$^{39}Y^{91m}$	GI(SI)	9,000
$^{39}Y^{92}$	GI(ULI)	200
$^{39}Y^{93}$	GI(LLI)	90
$^{40}Zr^{97}$	GI(LLI)	60
$^{41}Nb^{97}$	GI(ULI)	3,000
$^{43}Tc^{96m}$	GI(LLI)	30,000
$^{43}Tc^{99m}$	GI (ULI)	20,000
$^{44}Rh^{105}$	GI(ULI)	300
$^{45}Rh^{103m}$	GI(S)	30,000
$^{49}In^{113m}$	GI(ULI)	3,000
$^{49}In^{114m}$	GI(LLI)	60
$^{49}In^{116m}$	GI(ULI)	1,000
$^{53}I^{132}$	Thyroid	90
$^{53}I^{133}$	Thyroid	10
$^{53}I^{134}$	Thyroid	100
$^{53}I^{135}$	Thyroid	30
$^{55}Cs^{134m}$	Total Body	80
$^{59}Pr^{142}$	GI(LLI)	90
$^{60}Nd^{149}$	GI(LLI)	900
$^{63}Eu^{152}$	GI(LLI)	200
$^{64}Gd^{159}$	GI(LLI)	200
$^{66}Dy^{165}$	GI(LLI)	1,000
$^{68}Er^{171}$	GI(ULI)	300
$^{74}W^{187}$	GI(LLI)	200
$^{75}Re^{186}$	GI(LLI)	200
$^{76}Os^{191m}$	GI(LLI)	9,000
$^{77}Ir^{194}$	GI(LLI)	90
$^{78}Pt^{197m}$	GI(ULI)	3,000
$^{81}Tl^{202}$	GI(LLI)	300